

PRESENTATION

DRY TAPE BATTERY

FOR

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D.C.

15 JANUARY 1964

GPO PRICE \$ _____
CFSTI PRICE(S) \$ _____
Hard copy (HC) 300
Microfiche (MF) 52

ff 653 July 65



FACILITY FORM 602

N65-30486

(ACCESSION NUMBER)

(PAGES)

CR 64219

(NASA CR OR TMX OR AD NUMBER)

(THRU)

(CODE)

(CATEGORY)

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B O S T O N
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EVERETT 49, MASSACHUSETTS

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DRY TAPE BATTERY PROGRAM

I. INTRODUCTION

This report contains brief background information on a new concept in battery systems utilizing a dry tape continuous feed of active components. Included is the concept itself, inherent advantages, accomplishments to date along with some specific data, and considerations on both future plans and possible applications. It is hoped that sufficient information is presented, both to permit an understanding of the system and its capabilities and to provide stimulus for active consideration of its far reaching potential through many possible variations.

II. DRY TAPE CONCEPT

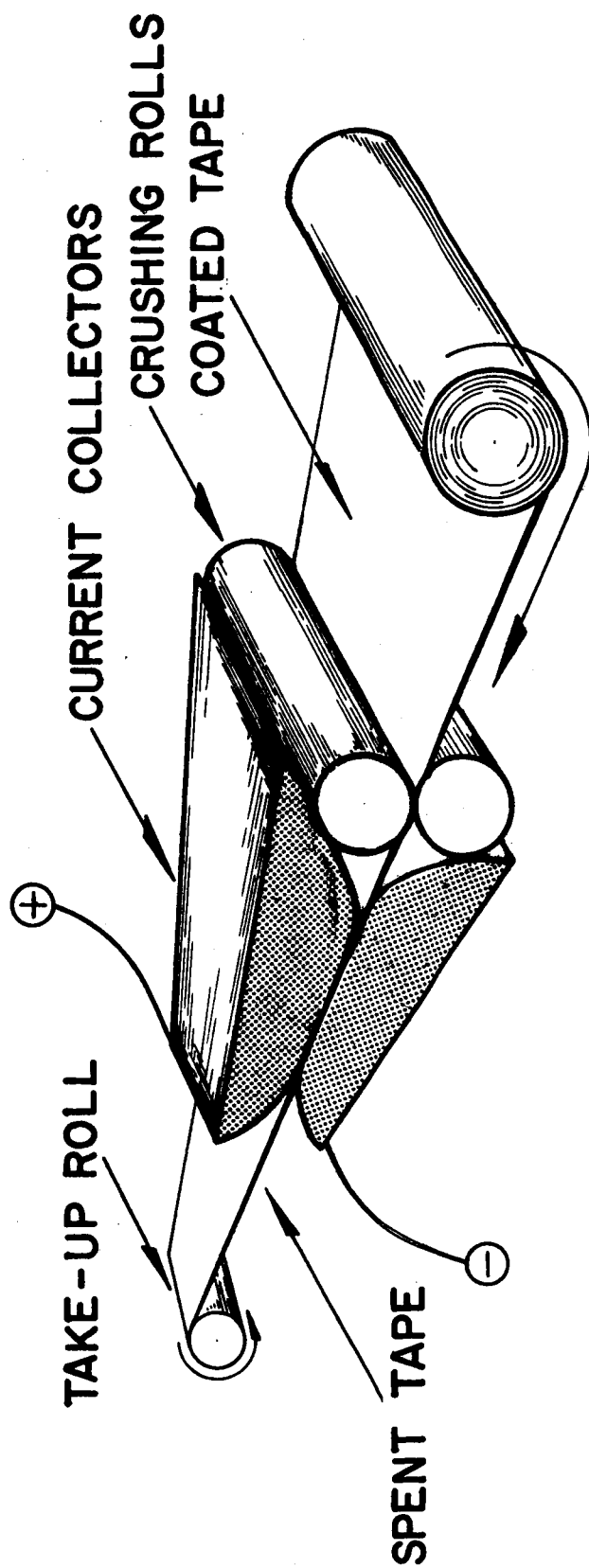
The major distinction between primary batteries and fuel cells is a matter of system invariance. A primary cell is completely self-contained; during operation, fuel and depolarizer are depleted while waste reaction products accumulate. In a fuel cell, we attempt to provide a more nearly invariant system by continuously feeding reactants and withdrawing products. While this allows us to maintain a more nearly constant system, it is still not completely invariant since separators degrade, catalysts become poisoned and electrodes can flood. Furthermore, mass transport or diffusional processes often limit the operation of both batteries and fuel cells, although generally this problem is more severe with batteries than it is with fuel cells.

The dry tape concept is designed to minimize, if not eliminate, some of these common failings of both batteries and fuel cells. The end result is a step towards more complete system invariance by feeding not only the fuel and oxidant but also the separator, electrodes, catalyst and electrolyte.

Figure 1 shows a schematic representation of the dry tape concept in its simplest form. Seen on the right is a spool of either an ion exchange membrane or a porous separator tape. On one side of this tape is a film coating containing the fuel while on the other side, the oxidant is similarly coated. The electrolyte is encapsulated and applied with either or both coatings. The crushing rolls serve to release the electrolyte locally so that the electrochemical reaction can take place while the tape is in contact with the current collectors. These current collectors are used to bring the current density down to reasonable levels at high current drain rates. In systems designed for operation at low drain rates, it would be possible to have the crushing rolls also act as the current collectors. After reaction, the spent tape is wound on a take-up spool for eventual disposal.

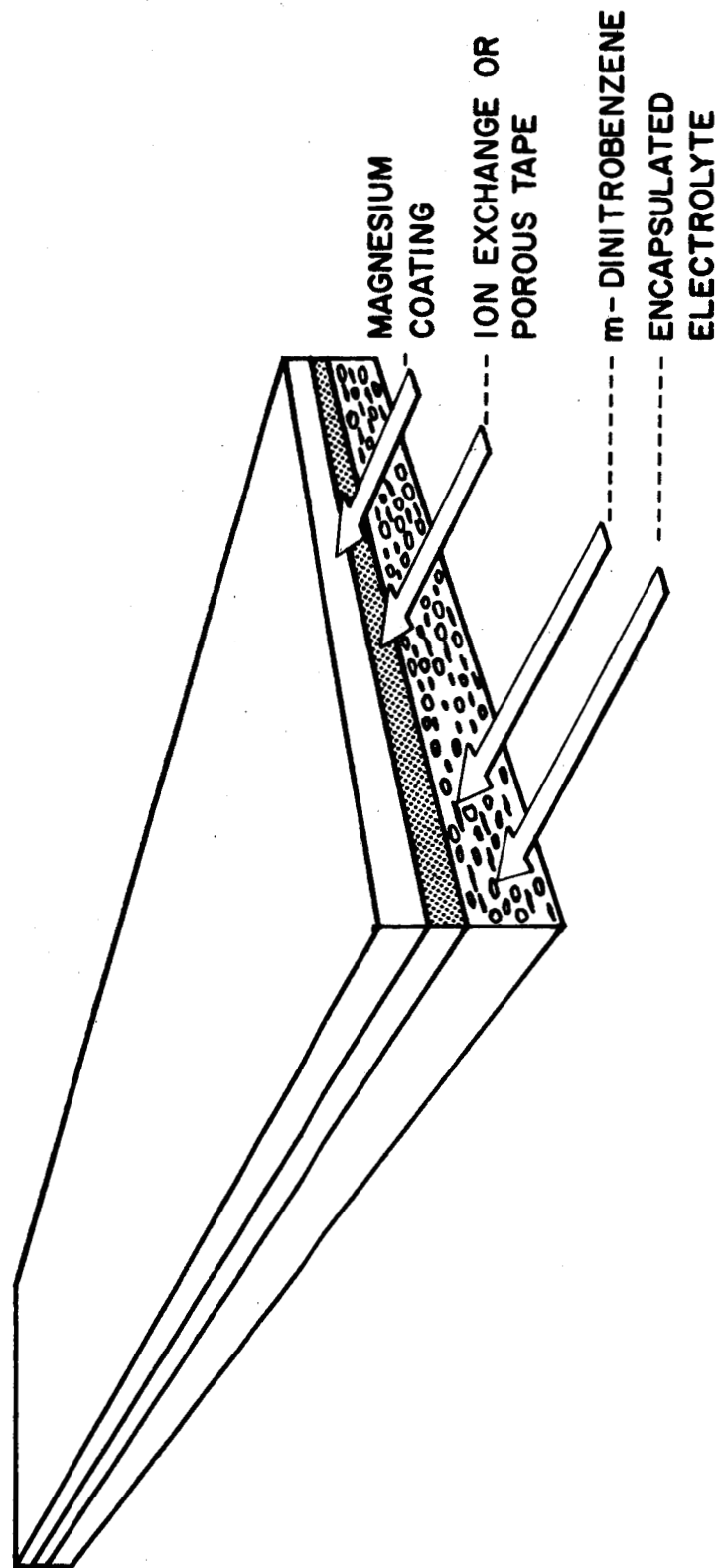
Many modifications of the mechanical portion of the system may be envisioned, but this picture serves to illustrate the basic principle of the concept.

The heart of the system is the coated tape. Fig. 2 shows a cross-sectional view of a tape based on the magnesium - meta - dinitrobenzene couple. The center shaded section can be either an ion exchange membrane or a porous separator tape. This would serve the normal functions of a separator and also provide the mounting base for the fuel and oxidant.



SYSTEM SCHEMATIC

FIGURE 1.



CROSS SECTION OF TAPE FOR Mg-META-M-DINITROBENZENE

FIGURE 2.

In this tape configuration, the magnesium fuel is applied as a thin foil in a stoichiometric amount. The underside of the tape is coated with the oxidant, which in this case is meta-dinitrobenzene, and micro-encapsulated electrolyte. Both the electrolyte microcapsules and the dinitrobenzene are applied to the tape as fine powders imbedded in a thin, water soluble polymer film for protection from the atmosphere. Such a film can be made from polyvinyl alcohol, polyvinyl pyrrolidone, or gelatin type materials. The total thickness of the coated tape would be 5 to 10 mils.

The electrolyte contained in the micro-capsules is completely isolated from the other electrochemical components. As the tape is fed through the crushing rolls, these micro-capsules are broken open and the electrolyte is released locally just before the tape enters the current collectors.

Although the electrolyte containment shown in Fig. 2 is by micro-capsules, other encapsulating methods, such as macro-capsules, are also possible. In the latter case, a system is envisioned whereby a series of pods are attached to the edge of the tape at predetermined intervals. The periodic crushing of these pods would release the necessary electrolyte. For certain missions, a third possibility is seen where it may be better for the electrolyte to be stored in a separate container and fed to the tape by a pumping system. In all probability, the type of electrolyte containment will be dictated by the overall mission requirements.

III. TAPE SYSTEM ADVANTAGES

From the foregoing, it should be appreciated that the dry tape concept is a hybrid fuel cell and battery. The fuel cell people may not think it a fuel cell, and the battery people might not consider it a battery but by whatever name it is an electrochemical energy conversion system with attractive advantages.

Foremost of these is a tremendous gain in energy density (watt-hours/pound). The stationary current collection system which is capable of handling an infinite length of tape electrode eliminates the need for any heavy electrode grid structure usually found in high-rate batteries. By the same token, wafer thin electrodes may be used with good volumetric efficiency thereby permitting highly efficient use of electrode active materials. This, coupled with the system's natural reserve capability, permits effective utilization of unusual, high energy density couples. A comparison with some existing systems is shown in Table 1.

Additional advantages over conventional batteries become apparent from the preceding discussion of the basic tape concepts and several of these are listed in Table 2. Of particular interest is the possibility of start/stop operation while still maintaining the unused tape in a truly "reserve", infinitely storable condition. Inherent within the tape system, also, is the elimination of separator shorting and maintenance of low internal resistance and steady output voltage, problems common to standard high-rate batteries.

TABLE 1

ENERGY DENSITY - SYSTEM COMPARISONS

WATT-HOUR PER POUND CAPACITY OF VARIOUS PRIMARY ELECTROCHEMICAL SYSTEMS

SYSTEM	EXPERIMENTAL CAPACITY WATT-HOURS/POUND	ESTIMATED MAX. CAPACITY WATT-HOURS/POUND
LE CLANCHE	35	70
Zn/KOH/HgO	45	65
Zn/KOH/Ag ₂ O ₂	75	90
Mg/MgBr ₂ /MnO ₂	65	90
Mg/Mg(ClO ₄) ₂ /m-DNB	100	130
Mg/m-DNB TAPE SYSTEM (100% C.E.)	--	245

TABLE 2

ULTIMATE TAPE SYSTEM ADVANTAGES

1. High Energy Density
2. Infinite Shelf Life
3. Separator Shorting Problem Eliminated
4. Low Internal Impedance Maintained
5. Continuous Renewal of Electrode, Separator, and Catalyst
6. Reserve Capability Maintained with Start-Stop Operation
7. Logistic Advantage in Transporting Tape Rather Than Battery
8. High Rate System with Low Rate Couples
9. Programed Power

IV. DETAILED PROGRAM

In June of 1963, NASA let a contract to Monsanto Research Corporation for the development and feasibility proof of the dry tape battery concept. This was a six month effort broken down into two major phases.

In the first phase methods of coating porous tapes with cathode materials were investigated. These coated tapes were then evaluated in a flexible laboratory device that could test tapes of various configurations and methods of electrolyte activation. With this device the operating parameters of coated tapes were established so that a bread-board demonstration device could be designed and built. During the second phase these devices were built and a quantity of coated tape to be used in them was produced.

The major object of this work was to demonstrate the feasibility of feeding a coated tape to a set of current collectors and withdrawing electrical energy.

A. Design Basis

Since this was to be a six month program, it was decided to use the following design basis.

1. Silver peroxide would be used as a cathode material. This would allow direct comparison with the performance of known battery systems.
2. Rather than attach a metal anode foil on the opposite side of the tape, the tape with cathode material on one side was passed over a zinc block which acted both as anode and current collector.

3. For the purposes of this study methods of micro or macro-encapsulation of electrolytes would not be investigated. Instead, mechanical means for supplying the electrolyte to the tape would be incorporated.
4. The demonstration units to be delivered to NASA would be designed to use off-the-shelf components insofar as possible. No effort at minimizing system weight or volume would be made at this time.

B. Tape Development

Production of a suitable coated tape involved selection of a base material, binder, and coating method for applying silver peroxide to the base material in a form suitable for discharge.

1. Tape Base Materials

Table 3 shows some of the base tape materials investigated in this work. It was not intended to make an exhaustive study to select the best base material, but rather to find as quickly as possible a satisfactory tape which could be used in the demonstration devices. Each of the tapes listed had certain advantages and certain drawbacks. The best selection appeared to be the non-woven polypropylene. This material provided good wet-out characteristics, adequate strength and allowed uniform coatings of the cathode material.

2. Tape Coating

Table 4 shows some of the binder materials investigated for attaching the silver peroxide to the tape. Polyvinyl alcohol was selected as

TABLE 3
PHYSICAL DATA ON TAPE BASE MATERIALS

Number	Type	Thickness mils	Weight g/in. ²	Electrolyte Retention 30% KOH g/in. ²	Manufacturer	Miscellaneous
N561	Non-woven nylon	3-4	0.034	0.135	Pellon Corp.	
2505K	Non-woven nylon	5-6	0.038	0.115	Pellon Corp.	
2505	Non-woven nylon	8-10	0.038	0.33	Pellon Corp.	
2505B	Non-woven nylon	10-12	0.038	0.35	Pellon Corp.	
N524	Non-woven nylon	60	0.032	0.80	Pellon Corp.	
EM403	Non-woven Dynel	0.8	0.012	0.04	Kendall Co.	
EM436	Non-woven Dynel	5-9	0.027	0.04	Kendall Co.	
EM476	Non-woven Polypropylene	2-7	0.023	0.04	Kendall Co.	
ML410	Non-woven Dynel	3-7	0.029	0.10	Millipore Filter	1.5 micron holes
OH 1.5	Porous Polyethylene	6-7	0.027	0.05	Millipore Filter	10 micron holes
OS10	Porous Polyethylene	9-10	0.034	0.03	Gelman Instrument	Nylon reinforced weak acid type, 5 micron holes (dry)
GWA	Ion exchange membrane	5	0.038	0.19	Gelman Instrument	Nylon reinforced polyvinyl alcohol, 5 micron holes (dry)
G FVA	Semipermeable membrane	5	0.038	0.04	Gelman Instrument	

TABLE 4

BINDERS

	Gelvato ^R 20-30	Methocel ^R 65HQ	PVP K-30	CMC 7HCP	Acrysol
Material	Polyvinyl alcohol	Hydroxypropylmethyl cellulose	Polyvinyl pyrrolidone	Cellulose gum	Polyacrylic acid
Manufacturer	Shawinigan Resins	Dow Chemical	Antara Chemicals	Hercules Powder	Rohm and Haas
Remarks		Slow to wet with strong KOH	Very slow to wet with strong KOH	Slow to wet with strong KOH	Produced brittle coatings, slow to wet

the binder for use in the devices inasmuch as it gave satisfactory operation and allowed freezing the design of the breadboard models at early date. In future work with other cathode materials more exhaustive studies of both base tapes and binder compositions are planned.

The coating mixture was made by dispersing the silver peroxide ultrasonically in water and adding an aqueous solution of polyvinyl alcohol. The resulting slurry was then applied to the base tape in known thickness by the use of a Gardener Knife. Generally, the loading of the silver peroxide in the dry polymeric binder was in the order of 90%. Higher loadings yielded poorly adherent coatings, while lower loadings generally resulted in poor wet-out and high resistivities.

3. Coating Analysis

A summary of per cent cathode active material (Ag_2O_2) analyzed in the tape coating as compared to that in the original slurry (dry basis) is shown in Table 5. The reasons for the small peroxide loss still occurring between slurry make-up and coating analysis are not fully known although a slight oxidation of the binder materials appears likely. Nevertheless, all efficiency calculations presented in this report are based upon the as made-up value rather than the measured percentage, making the results conservative, rather than optimistic.

Figure 3 illustrates the relationship between coating weight and thickness using polyvinyl alcohol binders and Nylon[®] base tapes. The vertical right hand scale is the equivalent of the coating weight in watt hours per square inch of tape. As can be seen from this plot,

TABLE 5

SUMMARY OF COATING ANALYSIS

<u>TAPE NO.</u>	<u>BASE MATERIAL</u>	<u>BINDER</u>	<u>COATING THICKNESS MILS</u>	<u>MAKE UP % Ag₂O₂</u>	<u>ANALYSIS % Ag₂O₂</u>
T-6	DYNEL	PVA	2-4	80	50
T-13	NYLON	PVA	6-8	90	75
T-22	NYLON	METHOCEL	3-5	94	88
T-24	POLYPROPYLENE	METHOCEL	3-4	94	89
T-27	NYLON	PVA	7-8	90	79
T-37	POLYPROPYLENE	PVA	4-5	92	78
T-44	POLYPROPYLENE	PVA	3-4	90	86
T-44A	POLYPROPYLENE	PVA- METHOCEL	5-7	90	86
T-52	POLYPROPYLENE	PVA	4-5	90	84
T-57	POLYPROPYLENE	PVA	3-5	90	83
T-60	POLYPROPYLENE	PVA	3-5	90	82
T-63	POLYPROPYLENE	PVA	3-4	91	84

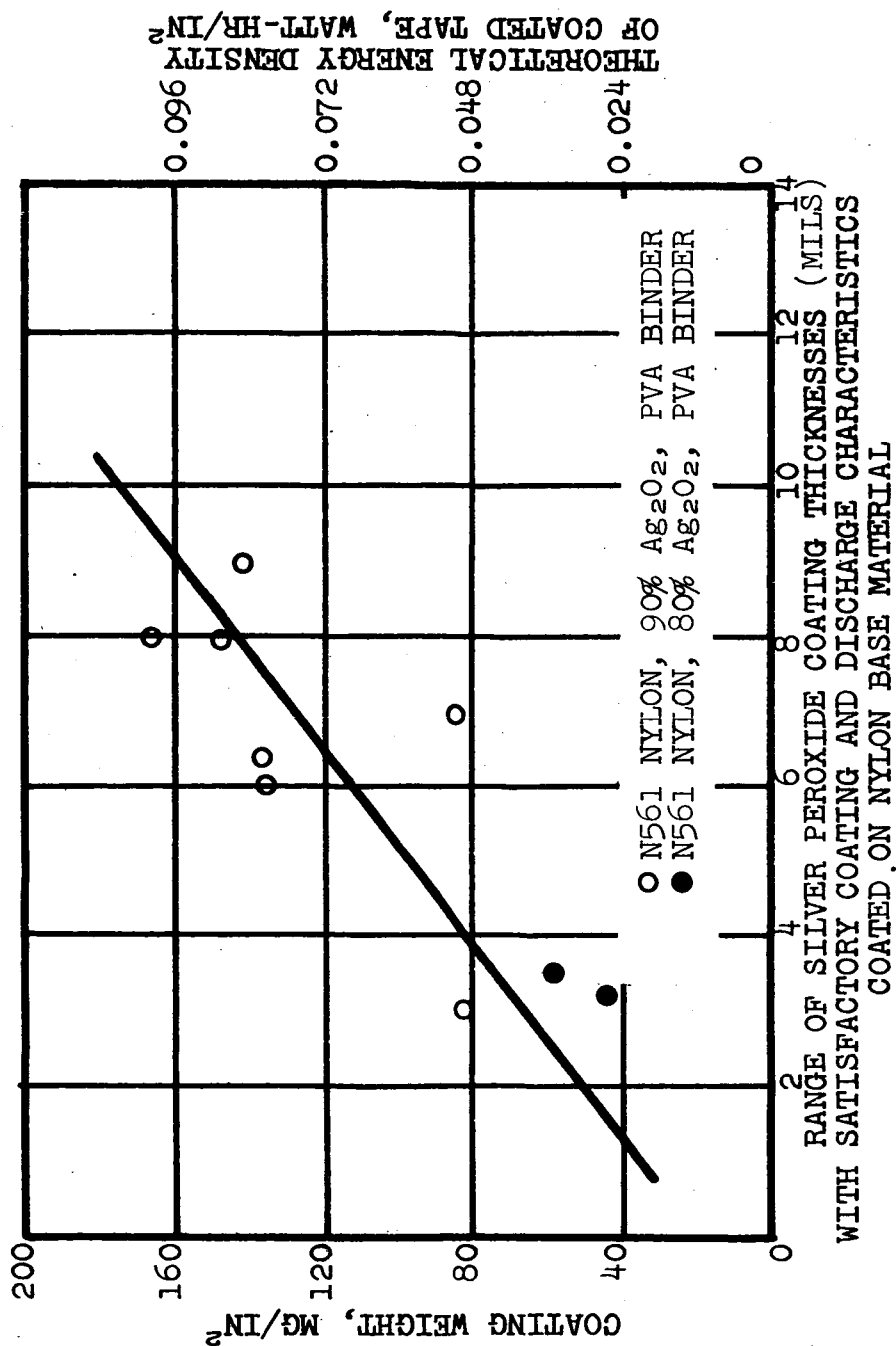


FIGURE 3

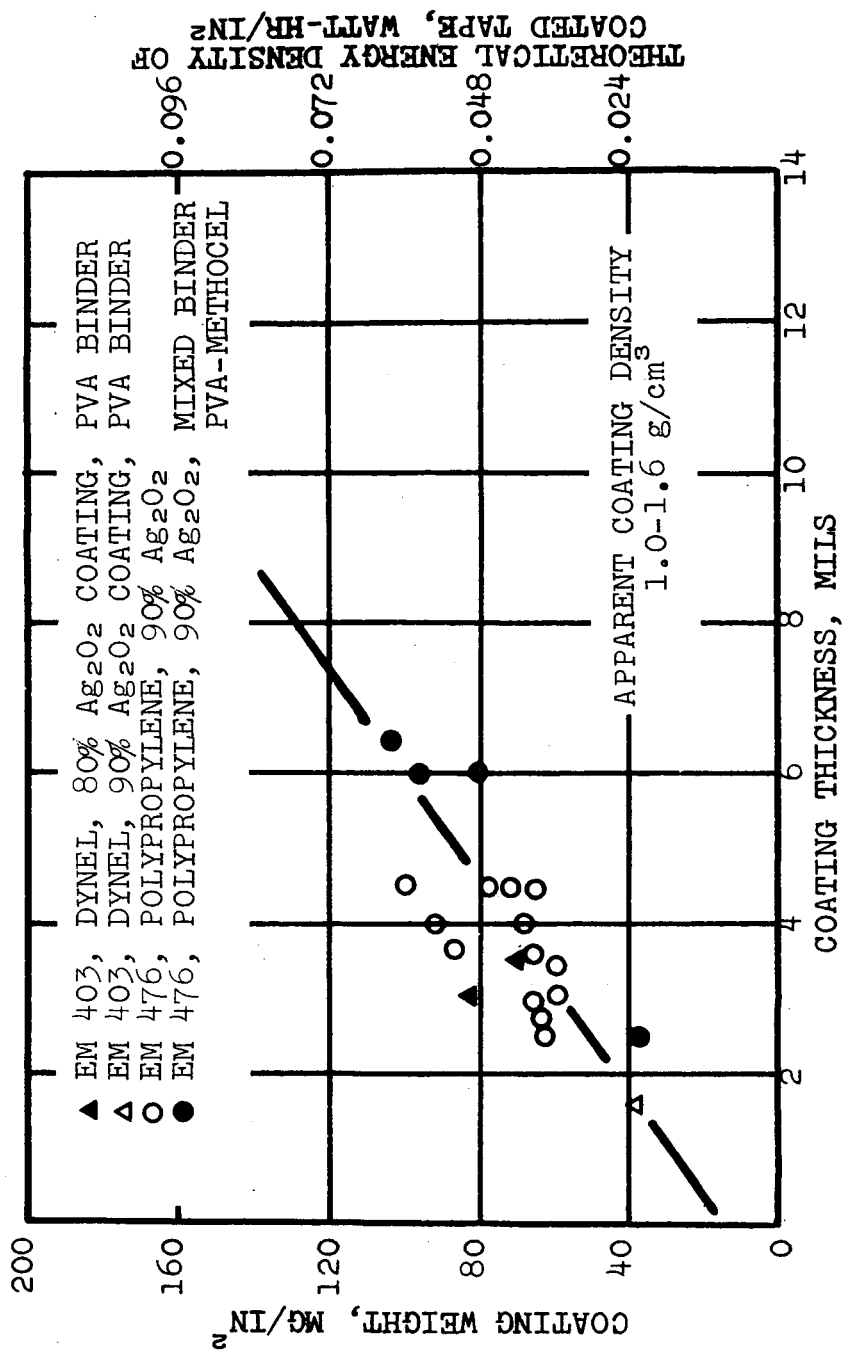
an energy density of 0.072 watt-hours per square inch is obtained with a coating thickness of only 6 mils. Included in the graph is the range of coating thickness and weights used in the feasibility study.

Shown in Figure 4 is a similar plot where Dynel[®] and polypropylene non-woven materials were used as the base tapes.

C. Laboratory Test Device

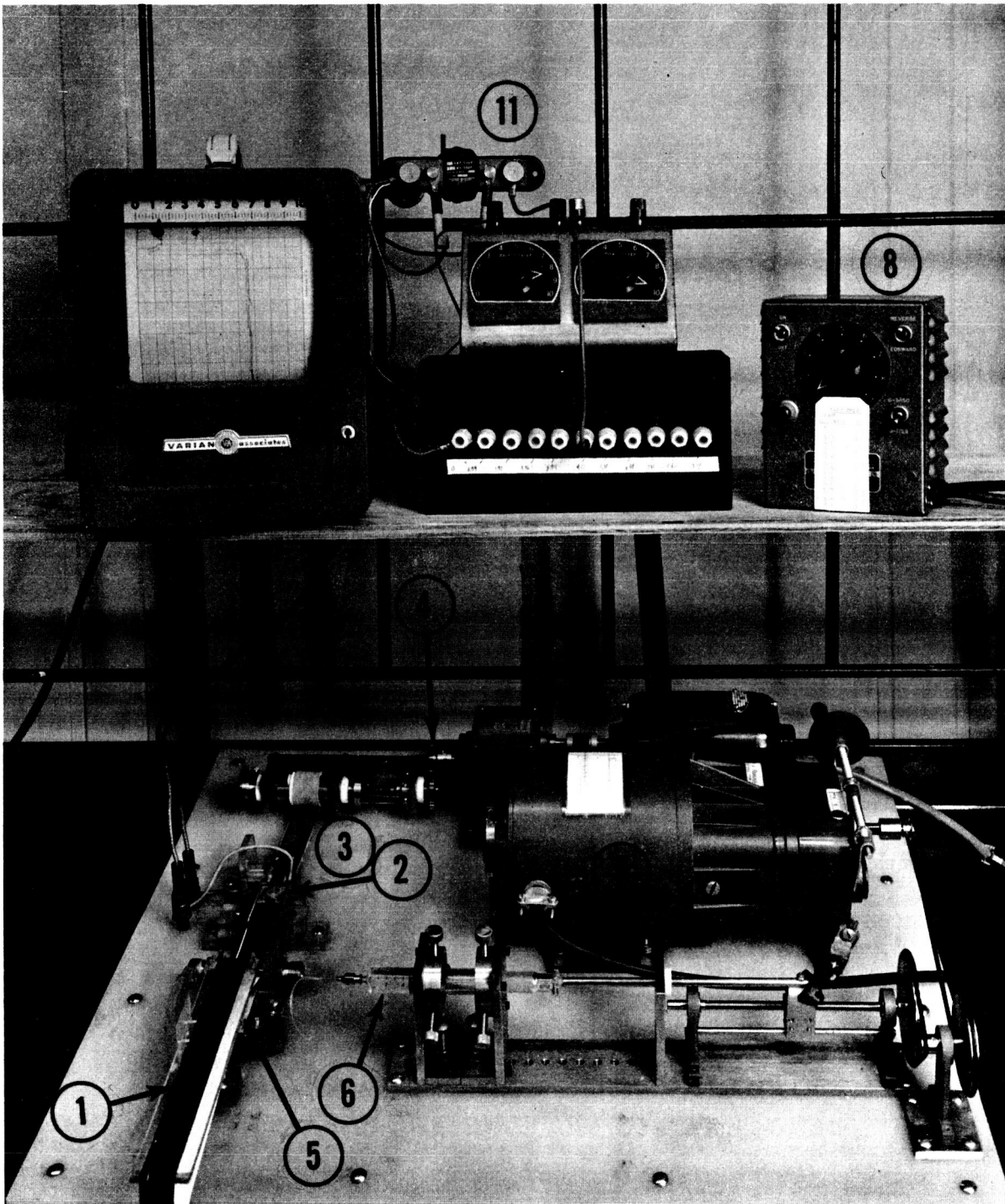
Figures 5 and 6 show the laboratory test device constructed to evaluate coated tapes. The following key is applicable to both photographs for dual-tape operation:

1. Dry tape, Ag_2O_2 coated
2. Current collectors
3. Take-up reel
4. Take-up drive motor
5. Electrolyte wicking pad
6. Electrolyte pump (micrometer syringe)
7. Zero-Max pump drive (variable speed)
8. Take-up speed control
9. Load box, 1 ohm steps
10. Dual pen recorder
11. 50 mV current shunt
12. Tape drive and torque meter
13. Separator tape, wet
14. Tape guide to cathode current collector
15. Wetted tape
16. Discharged tape
17. Contact rolls
18. Cathode current collector positioning screws



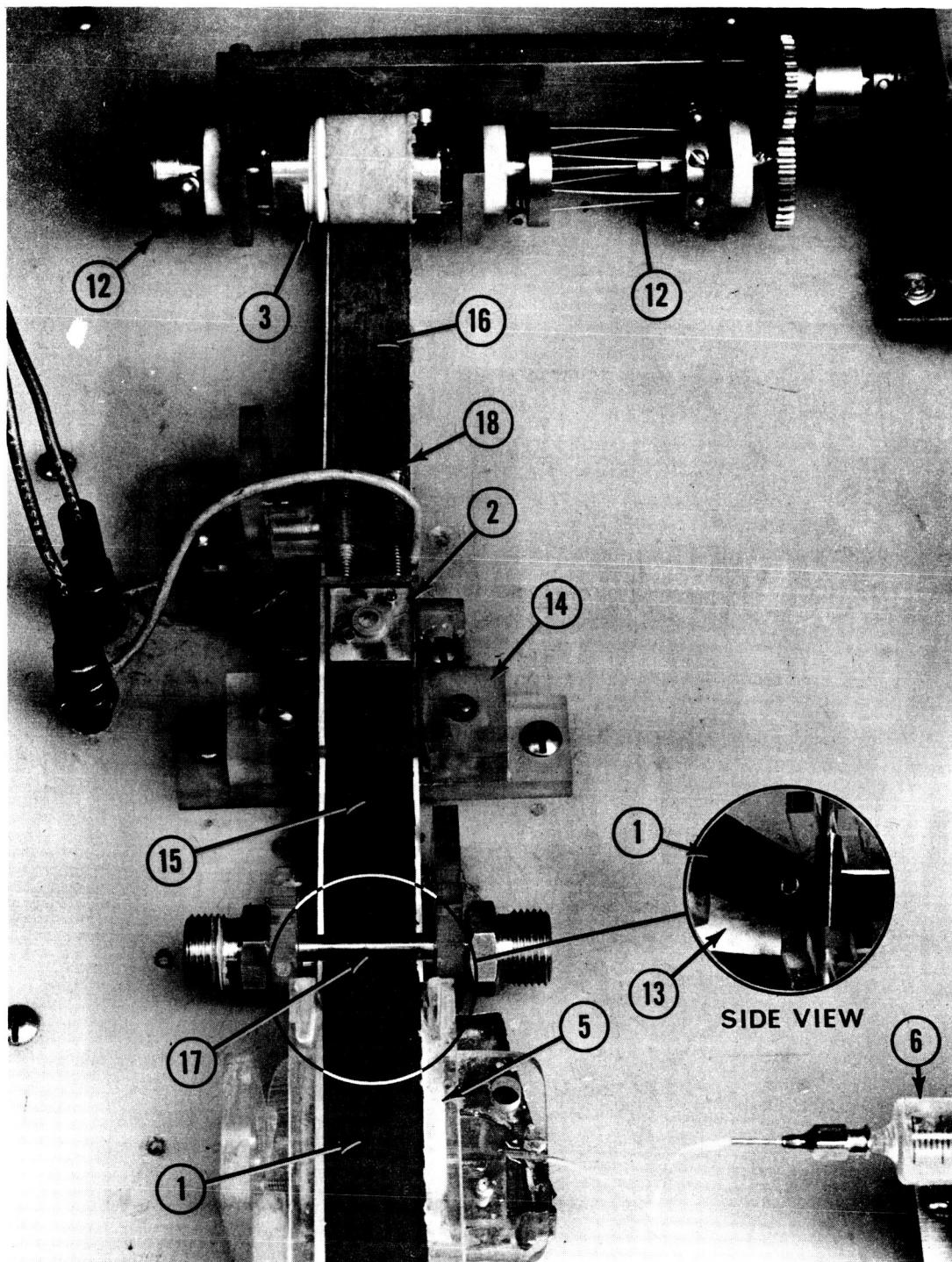
RANGE OF SILVER PEROXIDE COATING THICKNESSES
WITH SATISFACTORY COATING AND DISCHARGE CHARACTERISTICS
COATED ON DYNEL AND POLYPROPYLENE BASE MATERIALS

FIGURE 4.



LABORATORY TAPE DYNAMIC TEST DEVICE

FIGURE 5



TAPE SECTION OF DYNAMIC TEST DEVICE -
DUAL TAPE OPERATION

FIGURE 6

In operation, the separator tape is wetted with the electrolyte supplied from the micrometer feed syringe just prior to its contacting the coated tape. The two tapes in contact then enter the current collectors. The spent tape is wound on the take-up spool where the cage torque-meter measures the required pulling force. A variable speed motor and a standard gear reducer drives the take-up reel. The load box for the tape is seen on the upper shelf. To the left of this is a dual pen recorder for following the current and voltage outputs.

The enlarged view of the tape section of the laboratory test device (Fig. 6) shows more clearly the contact of the wet separator tape with the coated tape. The separator is wet with electrolyte at a wicking pad which is supplied by the syringe feed. The current collector, shown in the center portion of the picture, consists of both upper and lower sections. The upper collector is a silver block which contacts the silver peroxide coated tape while below is a zinc block which also serves as the anode.

The efficiency of the cathodic reduction is plainly visible in this photograph. The lower section of the tape, that closest to the bottom in the picture, is black and completely coated with the divalent silver oxide. On the other hand, once the tape has passed the current collectors it appears lighter in color. Actually, it is a light creamy yellow, indicating almost complete reduction of divalent silver to silver metal. The black specks or spots on the discharged portion of the tape were apparently low spots in the coating which did not contact the silver current collector.

D. Experimental Results and Discussion

1. Theoretical Energy Density of the Silver Peroxide-Zinc Couple

To provide a better basis for comparison of our results to those which can be theoretically expected, the basic electrochemical calculations for the zinc/silver peroxide couple are given below. The reaction chosen is that of divalent silver oxide reacting with two moles of potassium hydroxide plus two moles of zinc metal...this yielding two moles of potassium bizincate and two moles of silver metal.

The following electrochemical equivalents are used:

Ag_2O_2 - 2.3 grams per ampere hour: Zinc - 1.22 grams
per ampere hour

Potassium hydroxide - 1.04 grams per ampere hour (30%

KOH - 3.46 grams per ampere hour);

(37% KOH - 2.81 grams per ampere hour).

Based on these figures we can expect the maximum energy density of this couple to be:

Reactants - 149 watt hours per pound (dry KOH)

Reactants - (30% KOH) - 97 watt hours per pound

Reactants - (37% KOH) - 107.5 watt hours per pound

Data from a tape test run are given in Table 6. The quantity of zinc consumed was not determined experimentally but was assumed to be 10% in excess of that required theoretically. The amount of electrolyte required was also assumed to be 10% excess although considerably more was actually used with the particular separator involved.

TABLE 6

DATA ON TYPICAL TAPE TEST RUN

TAPE T-37TEST T-37-44913

TAPE SPEED - 0.25 IN/MIN

TAPE-POLYPROPYLENE 2.7 MIL + 4 MIL COATING 90% Ag_2O_2 , PVA Binder

ELECTROLYTE - 37% KOH SEPARATOR-10 MIL NYLON

ANODE - ZINC, 0.765 IN^2

OCV - 1.64 volts DISCHARGE - CURRENT 0.48 AMP

POWER - 0.67 WATTS VOLATAGE 1.40 VOLTS

TAPE WEIGHT - 0.12 GRAM/ IN^2 CURRENT DENSITY 89 AMP/FT

	<u>Ag_2O_2</u>	<u>BINDER</u>	<u>TAPE BASE</u>	<u>SEPARATOR</u>	<u>1.1 XTHERO. 37% KOH</u>	<u>1.1 XTHERO. ZINC</u>	<u>TOTAL</u>
WEIGHT (GRAM/HR)	1.12	0.09	0.35	0.50	1.47	0.64	4.17
WEIGHT PERCENT	27.1	2.2	8.4	12.0	35.2	15.1	

2. Summary of Tape Test Results

A tabulation of the results obtained using various types of base material, tape speeds, and current densities is presented in Table 7. It should be remembered that the per cent cathode utilization shown in this tabulation is calculated from the silver peroxide content of the tape as made up rather than as analyzed.

In the last two lines, energy density in watt hours per pound is shown for two conditions, the dry peroxide coated tape alone, and for the tape system including the separator and 1.1 times the theoretical amount of 37% KOH and zinc.

Figures 7 through 11 show some of the data correlations obtained in testing tapes of various types. In viewing these figures it should be kept in mind that our objective in this 6 month study was to produce a device which would demonstrate the feasibility of the concept, rather than to perform a research and development effort to perfecting it. In many cases, the data obtained could not be correlated from run to run. For example, it would be desirable to know the effects and interactions of all the known variables; however, it was usually necessary to freeze a parameter such as tape speed or coating thickness just as soon as an operable value was found. This allowed us to proceed immediately with the design of the final breadboard units.

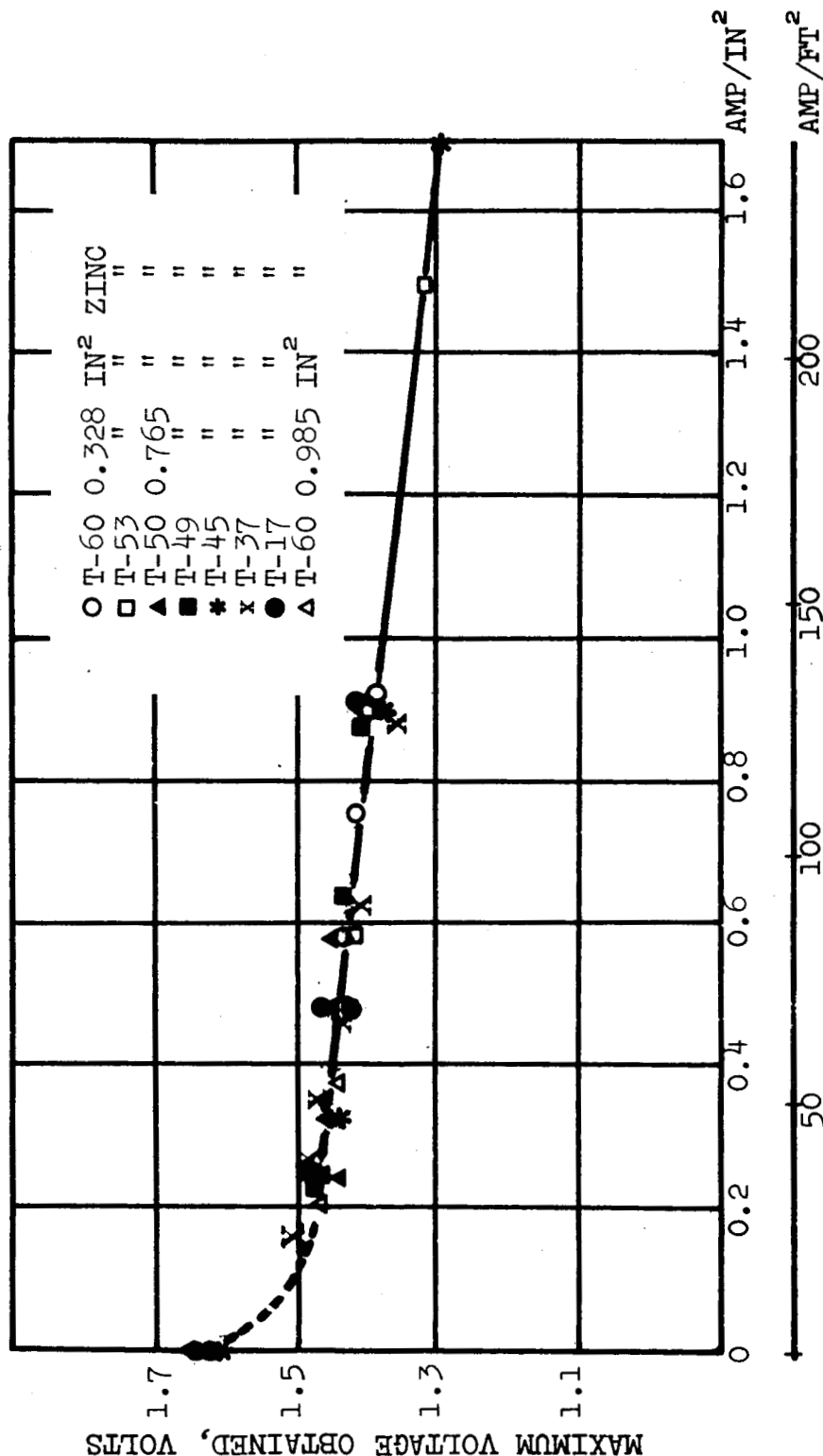
The relationship between the output voltage and current density obtained from various tapes is shown in Figure 7. The anode area varied from 0.328 square inches to 0.985 square inches, and in all cases, even though the anode area was changed, the voltage-current density relationship remains constant.

Table 7

SUMMARY OF TAPE TEST RESULTS ON LABORATORY TESTER

<u>Base Material</u>	Polypropylene								Nylon			Dynel	
	<u>Tape No.</u>	T-63	T-57	T-37	T-60	T-24	T-44A	T-52	T-44	T-22	T-13	T-27	T-6
<u>Current Density</u> amp/ft ²	36	36	37	89	110	124	127	175	216	116	122	230	91
<u>Tape Speed</u> in./min	0.25	0.2	0.2	0.25	0.2	0.75	0.6	1.0	1.4	0.5	1.0	1.0	1.0
<u>Cathode Utiliza-</u> <u>tion</u> %	88	98	94	94	92	98	90	62	70	98	78	75	83
<u>Energy Density</u> <u>Watt-hr/pound</u> of Ag ₂ O ₂ coated tape	156	190	188	188	174	170	156	103	111	137	94	108	54
<u>Watt-hr/pound</u> <u>of Reactants</u> <u>including</u> <u>separator</u>	63	58	54	54	67	58	64	44	48	55	55	49	29

CONDITIONS: ELECTROLYTE - 37% KOH; SEPARATOR - NYLON 10 MIL
 TAPE SPEED - 0.2 to 1 IN/MIN; BINDER - POLYVINYLALCOHOL



MAXIMUM VOLTAGE OBTAINED FROM SILVER PEROXIDE TAPES AS
 A FUNCTION OF CURRENT DENSITY FOR DIFFERENT ZINC COLLECTOR AREAS

FIGURE 7.

It should also be noted that our open circuit voltage is approximately 1.6 to 1.65 volts, considerably below the 1.86 open circuit potential of primary silver-zinc batteries. This has recently been shown to be caused, at least in part, by the silver current collector, where reaction of divalent silver oxide with metallic silver can take place to form the lower potential monovalent oxide. Substitution of an inert (gold-plated) collector has resulted in open circuit voltage more nearly the expected value. At a current density of 1 amp per square inch, the output voltage is about 1.4 volts, giving a voltage drop due to internal resistance of about 0.1 volts.

The utilization of silver peroxide as a function of current density is shown in Fig. 8 which represents the more recent results obtained. At a current density of 1 ampere per square inch, a cathode utilization of 85% was obtained, with this calculated on the as-coated weight of silver peroxide. The most critical requirements for obtaining high cathode utilization appear to be (1) a smooth coating with a minimum of binder present and (2) matching tape speed to drain rate.

The current densities vs the tape speed in inches per minute for various tape bases and coating thicknesses is shown in Figures 9 to 11.

For any coating thickness and given tape speed there is a theoretical maximum current which can be drawn from the system. This is shown by the straight line portion of the plots and labeled 100% cathode utilization. The actual test results are shown by the curved lines. The deviation of the curved line from the 100% utilization line gives an indication of the current efficiency at any of the tape speeds shown.

CONDITIONS: ELECTROLYTE - 37% KOH; SEPARATOR - NYLON 10 MIL
 TAPE SPEED - 0.2 to 1 IN/MIN; BINDER - POLYVINYLALCOHOL

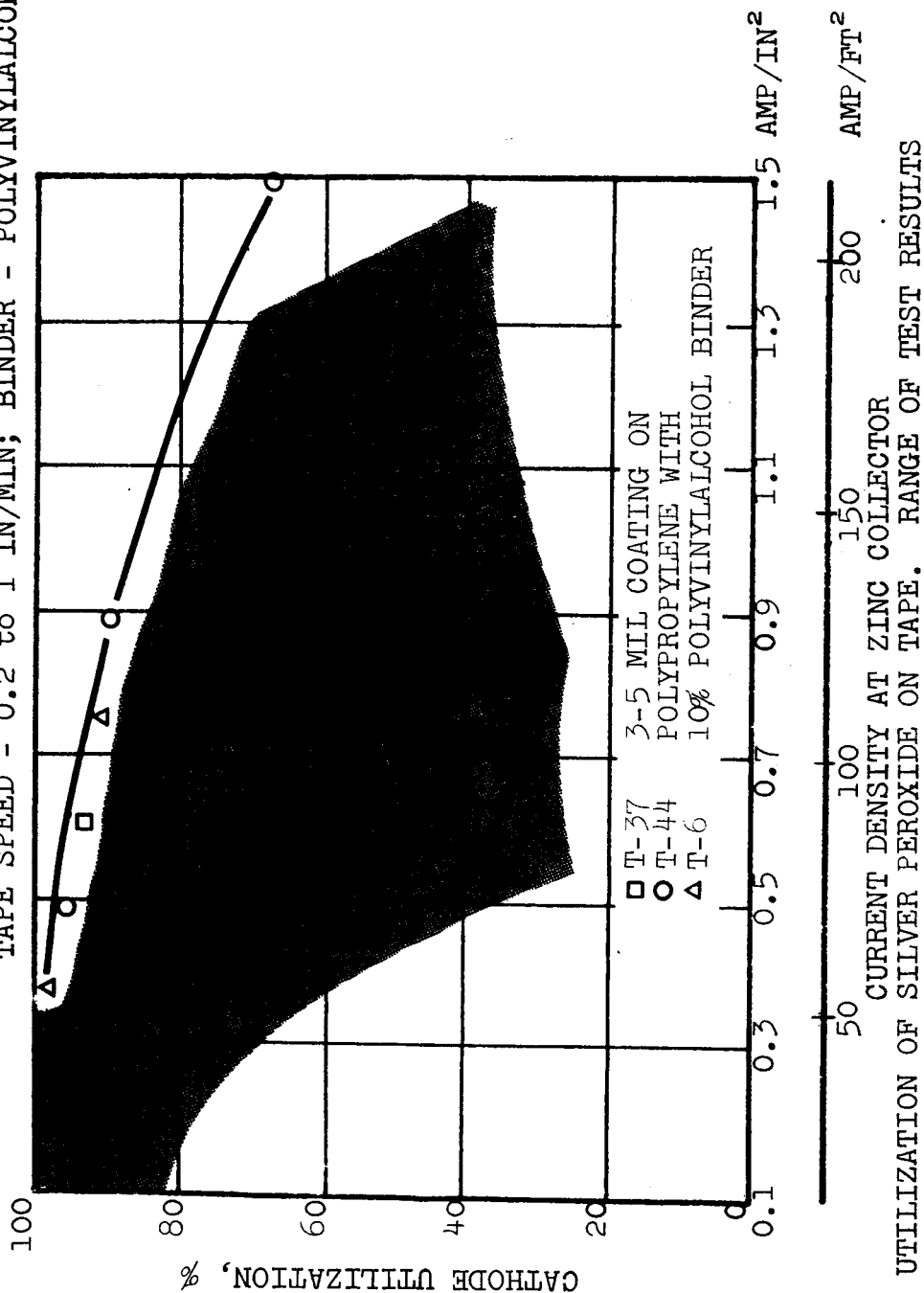
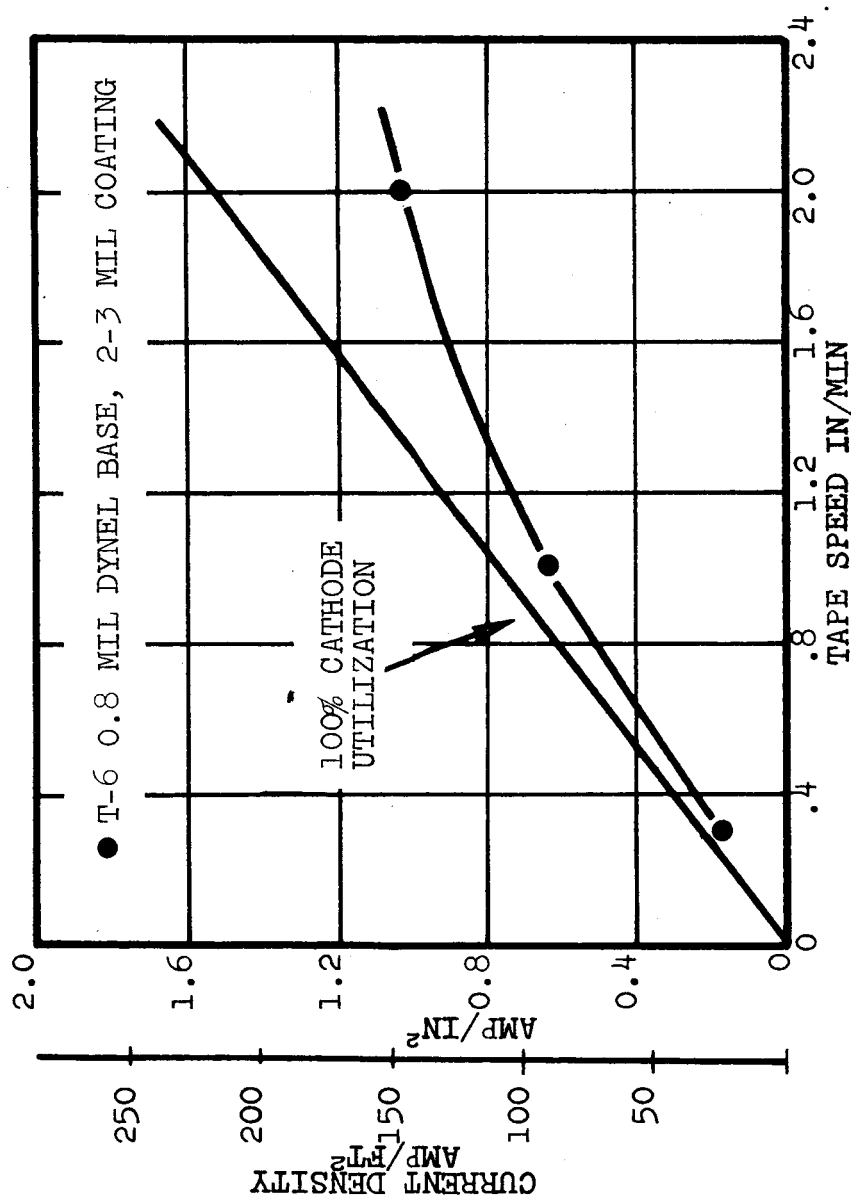
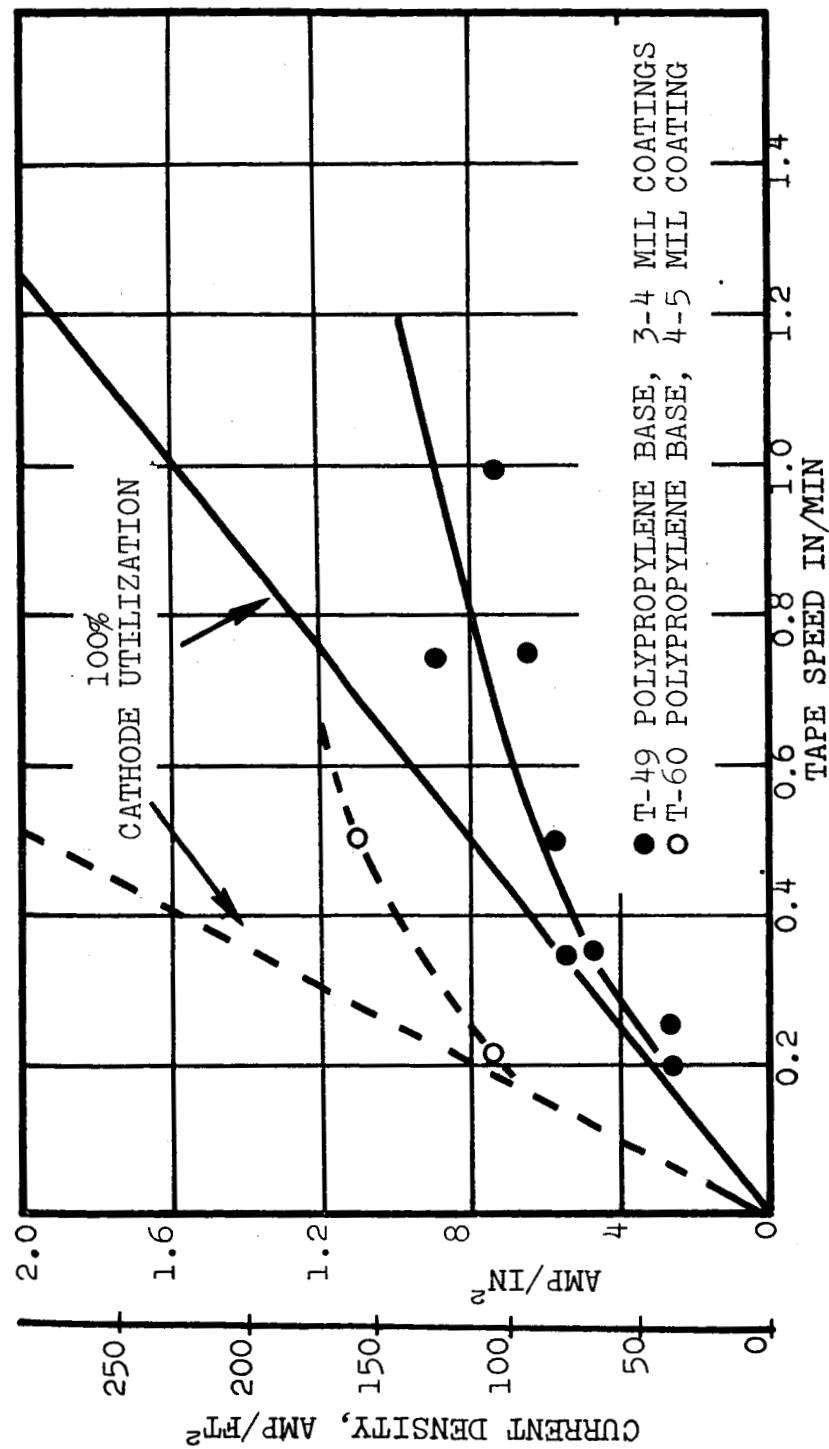


FIGURE 8.



EFFECT OF TAPE SPEED AND CURRENT DENSITY ON CATHODE UTILIZATION. ZINC ANODE, Ag_2O_2 CATHODE, KOH ELECTROLYTE

FIGURE 9.



EFFECT OF TAPE SPEED AND CURRENT DENSITY ON CATHODE UTILIZATION. ZINC ANODE, Ag_2O_2 CATHODE, KOH ELECTROLYTE

FIGURE 10

The current densities plotted on the vertical scales are the maximum ones which were obtained with a steady voltage output.

Two interesting points are noted in Figure 11. First, on the three to four mil coatings the actual experimental results do not fall off as drastically from the 100% utilization line as they did in the three to four mil coating results shown in Figure 10. This is probably due to a non-uniformity in the coating technique.

Secondly, the curves for the five to six mil coatings show a drastic leveling off when compared to the 100% utilization line. Several explanations are possible. This may again be due to a non-uniformity in the coating technique or it could mean that a limiting thickness of coating was reached beyond which more active materials could not be efficiently utilized at high speeds.

E. Hardware Development

Since this was a 6 month program aimed at producing four demonstration breadboard devices, it was necessary that the hardware development phase be carried on concurrently with the research involving tape fabrication. As a consequence of this, it was necessary to freeze the design of a workable tape configuration as soon as it was developed, even though its performance could be improved by further research.

One of the requirements of the contract was that the demonstration units be completely self-contained and powered by a spring wound motor. Because of the time limitations, it was necessary to use as many off-the-shelf components as possible. There was not time to design and develop all of the required components, particularly the spring wound motor.

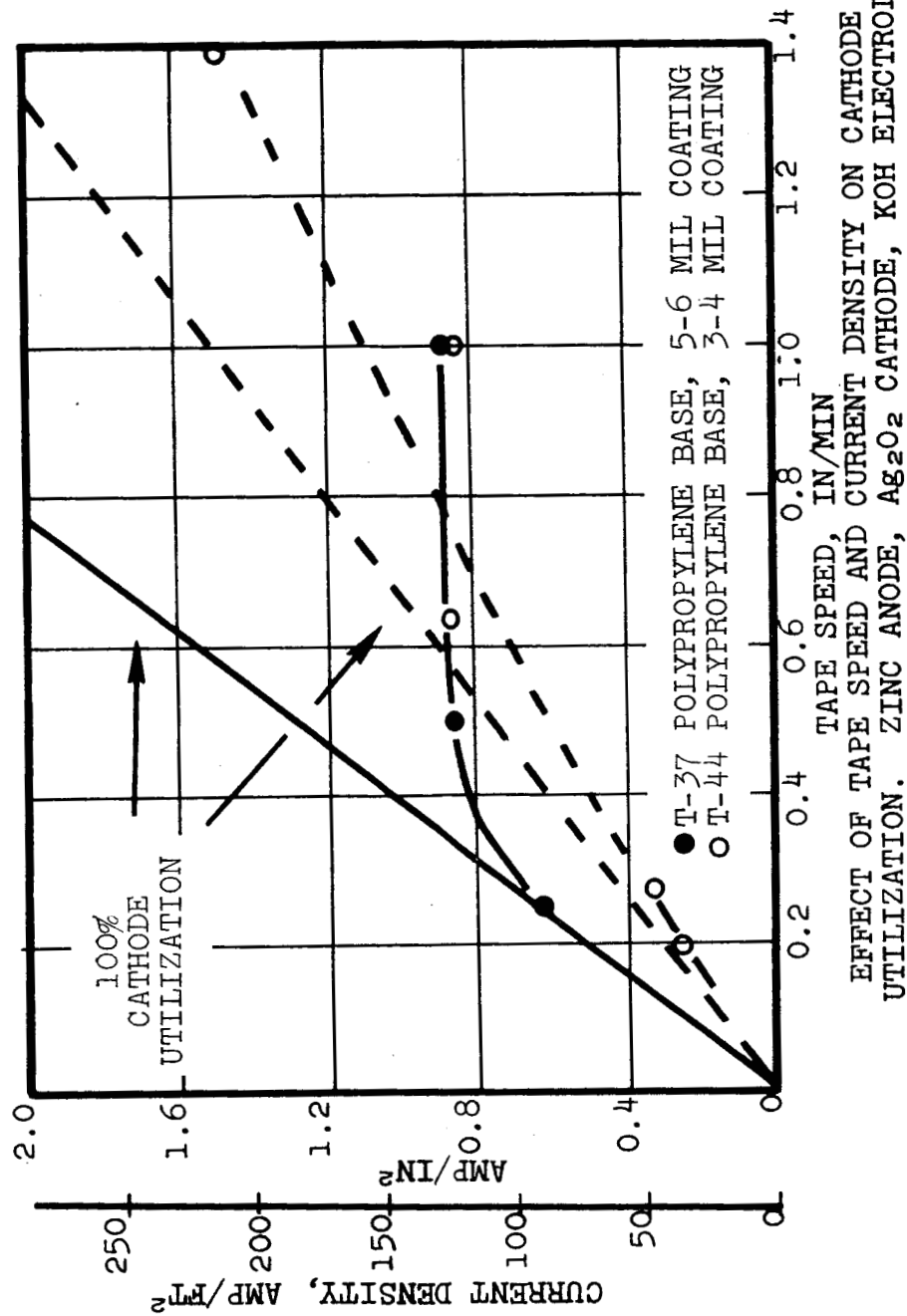


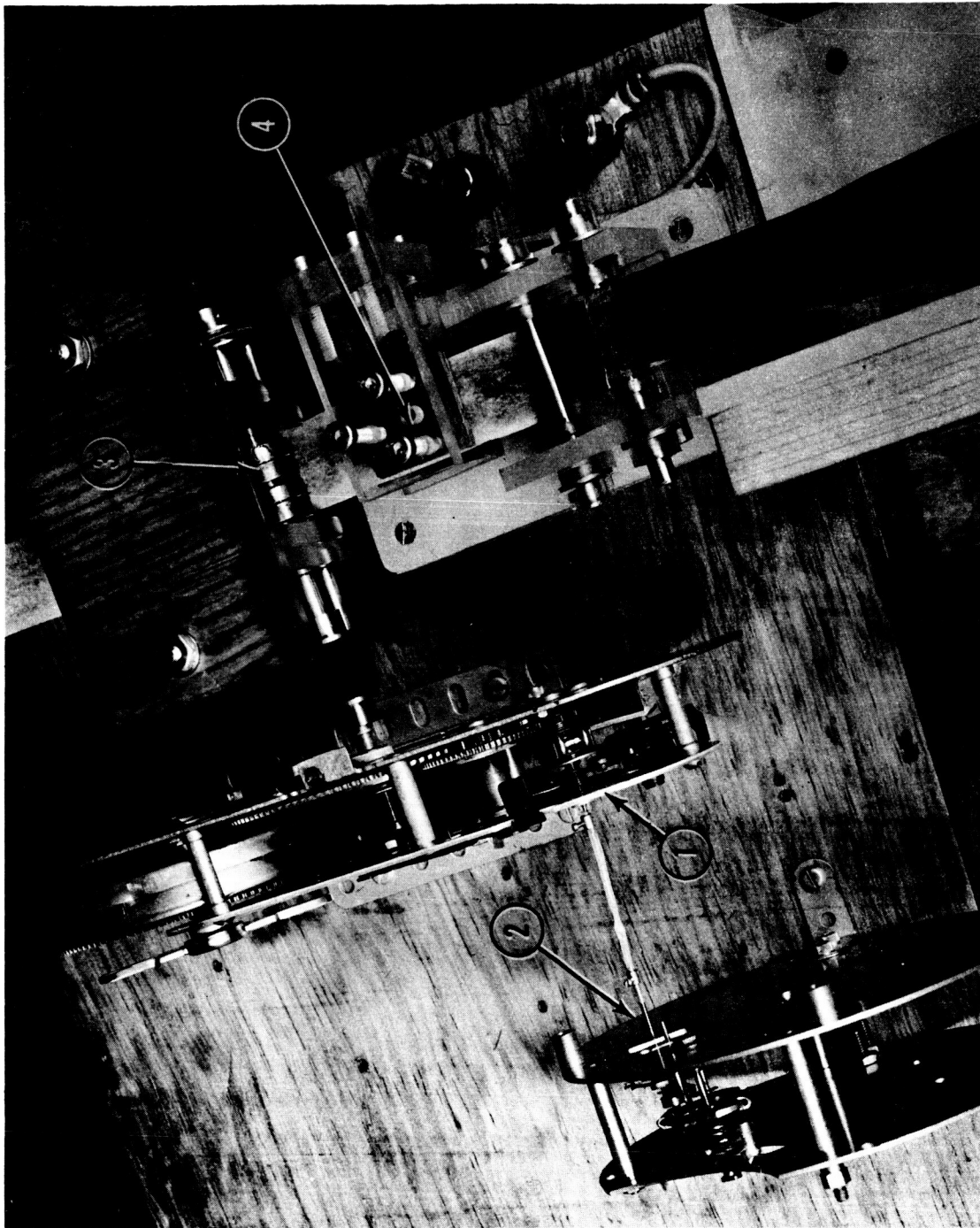
FIGURE 11.

As one would expect, a wide variety of spring motors was available, all of which were either oversized or undersized for our purposes. The motor closest to meeting requirements was found in a 16 millimeter movie camera. Although this unit contained sufficient energy storage, the speed governing device in the drive was such that it could not be slowed down enough to give the required tape feed of approximately 1 inch per minute. It was therefore necessary to attach a clock escapement mechanism to the governor shaft of the motor. This combination permits operation for 144 minutes on one winding.

The test stand for checking out the proposed breadboard components is shown in Fig. 12. The following key is applicable:

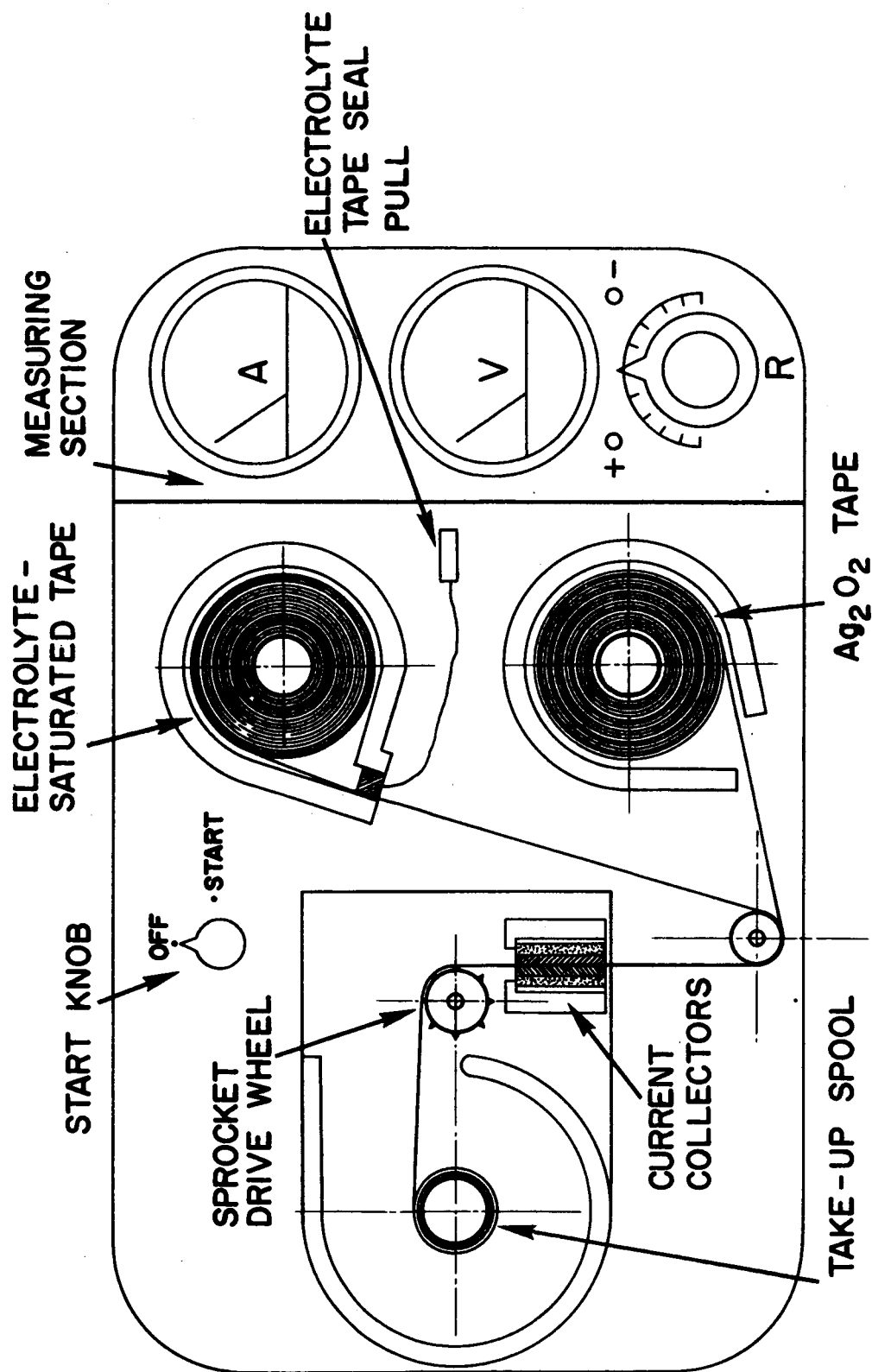
1. Spring wound motor
2. Escapement mechanism
3. Sprocket drive
4. Current collectors

Since electrolyte encapsulation was not to be investigated as part of this program a dual tape system was used in which the silver peroxide coated tape is wetted by another tape saturated with electrolyte. These tapes are mounted on a plate called a tape deck. Each is completely self-contained except for the drive unit. A total of 20 such decks were built, any of which can be plugged into a drive unit containing the spring wound motor. A plan view of the deck is shown in Fig. 13 while a composite sketch of deck and drive unit is seen in Fig. 14.



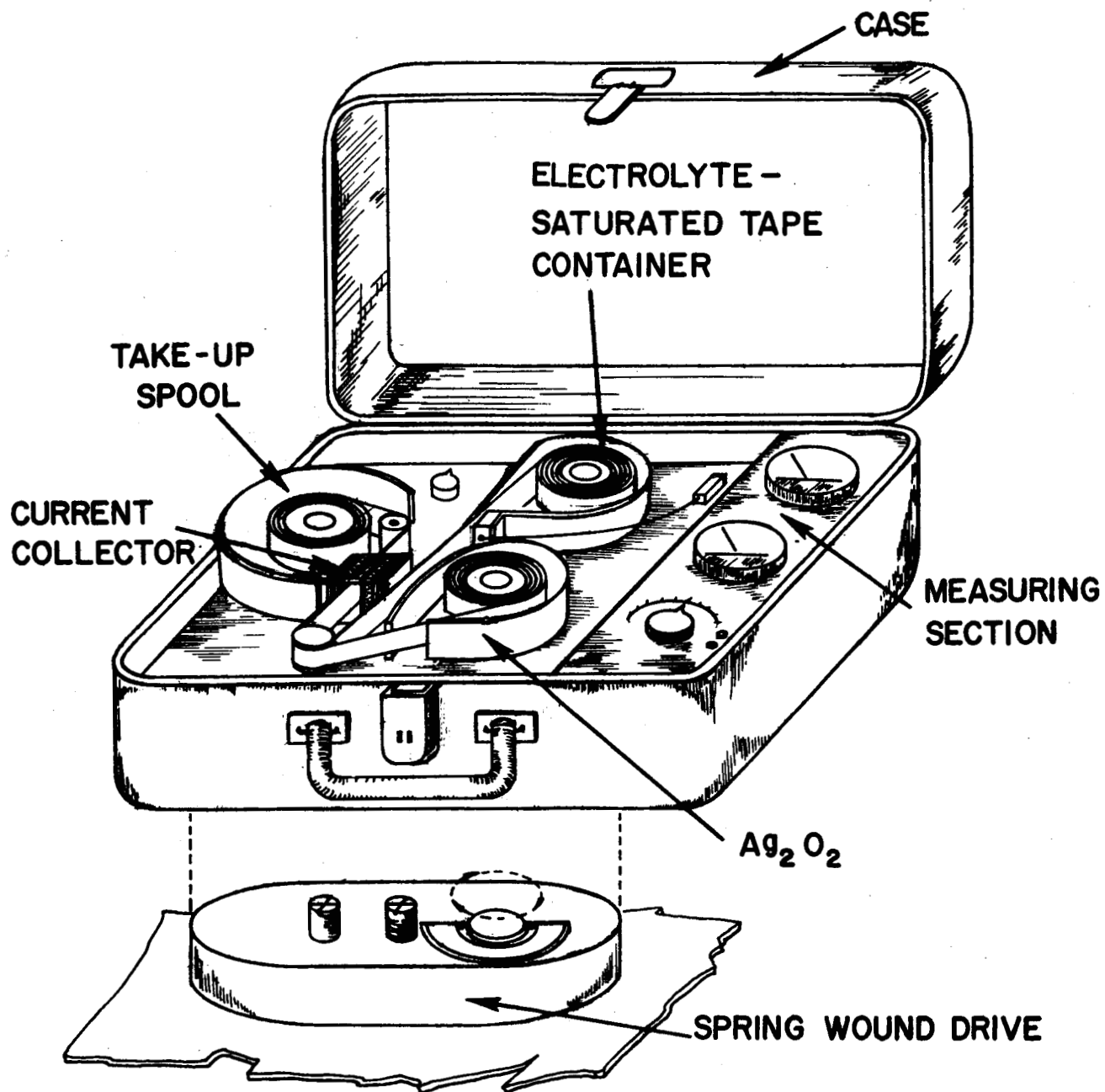
COMPONENT TEST STAND - TOP VIEW

FIGURE 12



PLAN VIEW OF TAPE DECK

FIGURE 13.



PROTOTYPE DEMONSTRATION MODEL OF DRY TAPE BATTERY
FIGURE 14

V. FUTURE PLANS

At the end of this 6 month period the feasibility of the tape concept has been established by continuously feeding a silver peroxide coated tape and electrolyte to a set of current collectors and withdrawing electrical energy. The breadboard devices built to do this are not final systems; they are simply demonstration units. The use of the zinc/silver peroxide couple again was a convenience. It does not represent the ultimate in high energy couples.

Accordingly, future plans call for continued development of the system into a more applicable end device as well as further research into exotic high energy couples for incorporation into the electrode structure. Briefly stated, future work may be summarized as follows:

1. Devise methods of incorporating high energy anodes and cathodes into tape systems.
2. Investigate various methods of encapsulating electrolyte.
3. Combine the highest possible energy couple into the one tape configuration.
4. Design a tape conversion device capable of supplying its own power for unattended operation.
5. Work out methods of supplying multiple cell voltages for the dry tape battery.

A. High Energy Anodes and Cathodes

Although most of the work to date has been with the zinc/silver peroxide couple, the next efforts will involve the use of high energy density anodes and cathodes.

One particular example of a high energy density system is the magnesium meta-dinitrobenzene couple. This seems to be an ideally suited one, since in a primary battery configuration its output is limited by mass transport or diffusion rather than thermodynamics. In present primary battery usage, it is a high energy density couple, capable only of low drain rates. Applying this couple to a tape could considerably improve its drain capabilities since the diffusional limitation is overcome by mechanically feeding the reactants to the reaction sites.

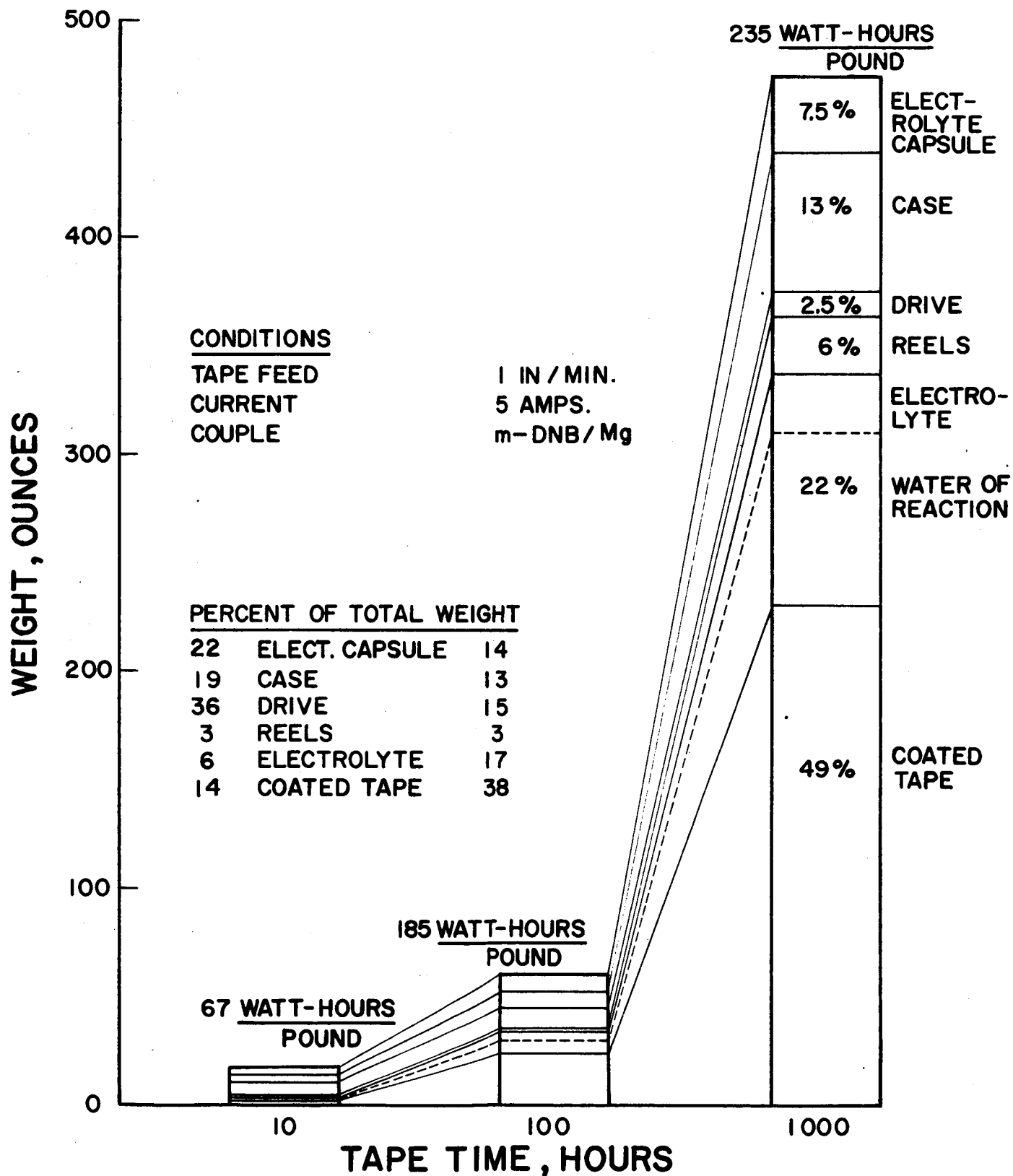
The magnesium/meta-dinitrobenzene couple has a theoretical energy density of 766 watt hours per pound of reactants, a figure which includes the 8 moles of water required in the reduction of each mole of meta-dinitrobenzene.

Figures 15(a) and (b) show the results of a system analysis based on the magnesium meta-dinitrobenzene couple applied to the tape.

Shown on the graphs is the total system weight in ounces as a function of mission time for individual periods of operation of 10, 100, 1000, 10,000 hours, and 5 years. For each of these bar graphs the tape feed rate is one inch per minute and the current output is 5 amps for the entire mission time. In each case the mechanical components for the entire system are scaled up versions of those used for the 10 hour mission.

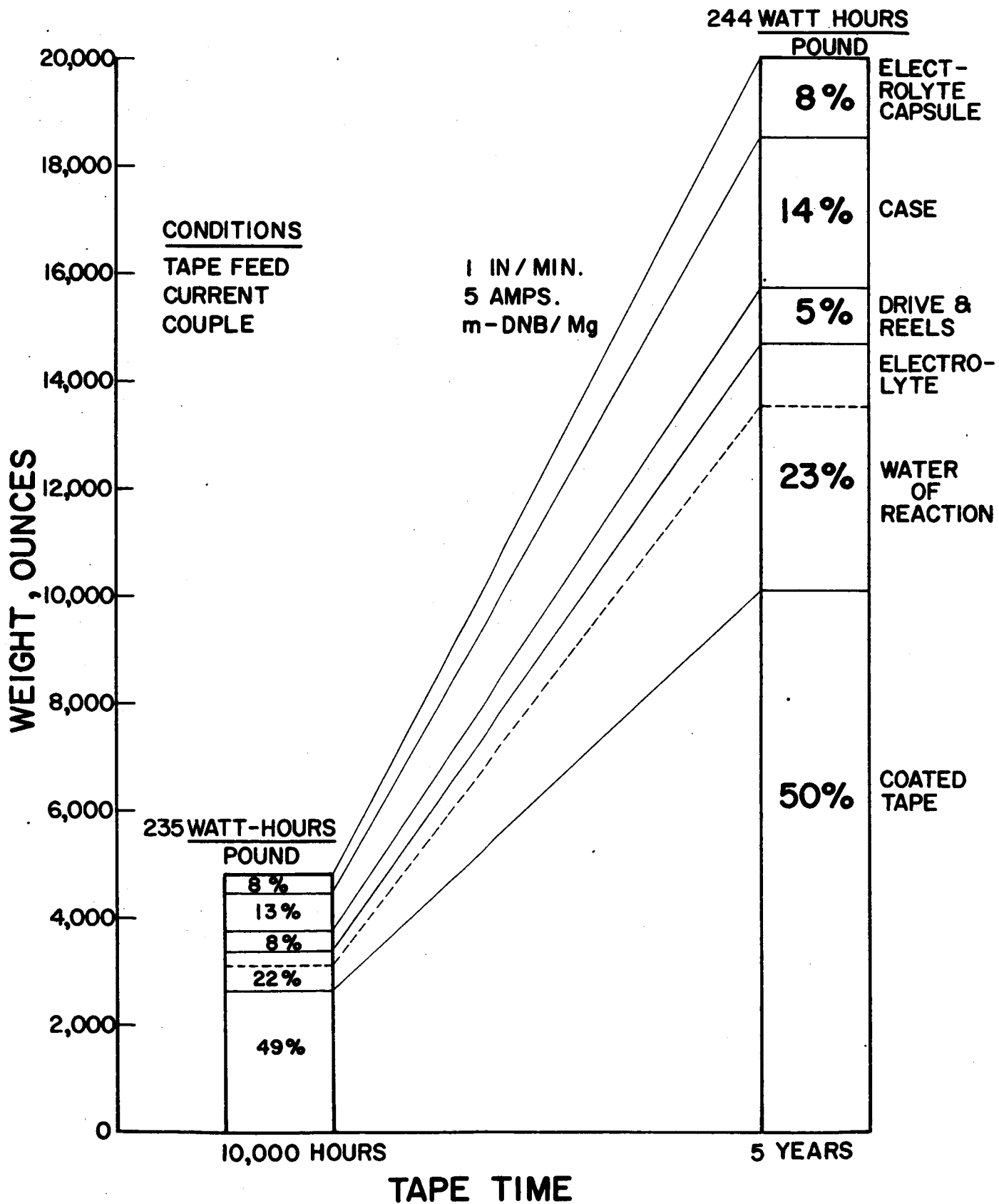
Considering the 10, 100, and 1000 hour mission times [Fig. 15(a)], it is seen that:

1. The electrolyte capsule weight goes from 22 to 14 to 7.5 per cent of the total weight.



SYSTEM ANALYSIS-MAGNESIUM-m-DINITROBENZENE COUPLE

FIGURE 15a.



SYSTEM ANALYSIS-MAGNESIUM-m DINITROBENZENE COUPLE

FIGURE 15b.

2. The weight of the case goes from 19 to 13 to 13 per cent of the total weight.
3. The weight of the drive goes from 36 to 15 to 2.5 per cent of the total weight.
4. The reels are constant at 3% for the 10 hour and 100 hour levels but rise to 6 per cent of the total weight for the 1000 hour mission.
5. The weight of the electrolyte rises from 6 to 17 to 22 per cent of the total weight. Here it should be noted that the dotted line represents the dividing point between the water required for the reaction of meta-dinitrobenzene and that of the electrolyte. It can be seen that the weight of the water of reaction is larger than that assumed for electrolyte. This proportionality is also carried but not too clearly seen in the 10 and 100 hour mission times.
6. The weight of the coated tape as a fraction of the total system weight rose from 14 to 38 to 49 per cent.

For the ten hour mission the total energy density is calculated to be 67 watt hours per pound; for the 100 hour mission 185 watt hours per pound; for the 1000 hour mission 235 watt hours per pound.

The same analysis is carried through in Fig. 15(b) for mission times of 10,000 hours and 5 years. Here, the point of maximum return has apparently been reached since the fractional weight of the active components do not increase and there is only a corresponding token rise in energy density.

B. Encapsulation

Three general ways of encapsulating the electrolyte are visualized whereby the system's liquid portion is isolated from the anode and cathode components. These are illustrated and compared in Figure 16.

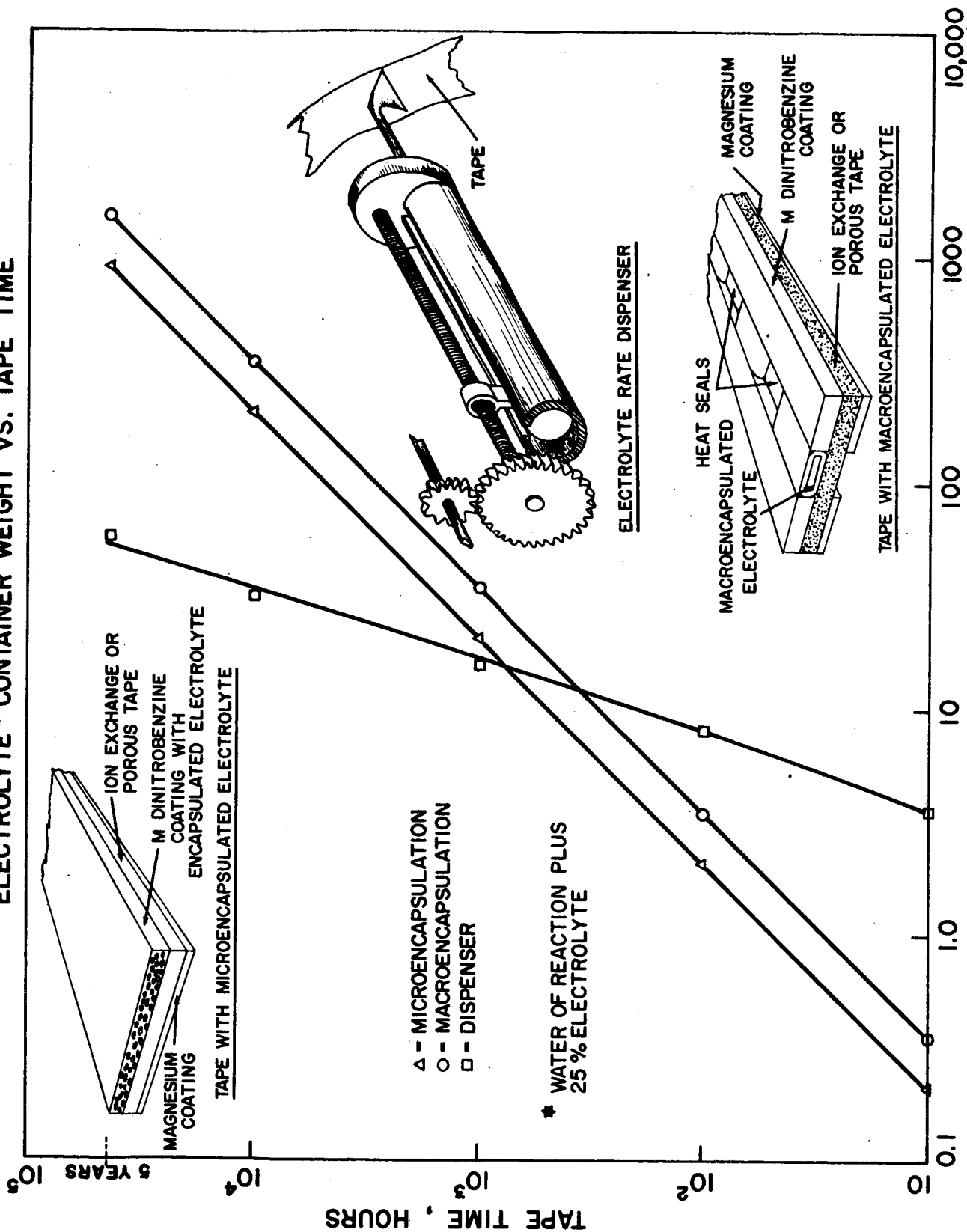
In the upper left hand corner is a schematic representation of electrolyte contained in micro-capsules and embedded directly in the cathode coating. These micro-capsules can be made as small as 5 microns in diameter with a wall volume of only 5% of the total capsule volume. The major problem with micro encapsulation is that the water permeability of the capsule wall is very high and at present it is not known whether it will be possible to achieve a long shelf life. Release of electrolyte is accomplished with smooth pressure rollers.

At the lower right portion is a schematic representation of macro-encapsulated electrolyte as applied to a coated tape. Here, electrolyte is contained in something similar to sausage links laid into the coated tape. Electrolyte release is caused by sprocket toothed rollers.

A third way of encapsulating the electrolyte is to store it in a completely separate container not attached to the tape at all. A schematic representation of such a system is shown at the upper right of Fig. 16. In this system the electrolyte for the entire tape length would be contained in a collapsible plastic bag supported in a rigid tube. A mechanical feed would squeeze the bag at a fixed rate extruding the electrolyte on to the tape for activation.

Superimposed on the 3 schematic drawings of Fig. 16 is a subsystem analysis which shows the variation of the container weight with time of operation in hours for each of these methods of encapsulation.

ELECTROLYTE* CONTAINER WEIGHT VS. TAPE TIME



COMPARISON OF METHODS FOR ELECTROLYTE ENCAPSULATION
FIGURE 16.

In general, micro-encapsulation would always seem to offer a weight advantage over macro-encapsulation, and both are better than the dispenser for mission times below 700 hours. However, for mission times greater than 700 hours the dispenser method offers the greatest weight advantage under the assumptions used in this analysis.

C. Parasitic Drive

Other work planned in the next phase includes the development of an electrical parasitic drive to operate directly from the power output of the tape. This unit will also have start-stop capabilities.

In our work on the silver/zinc system we have actually measured the power required to pull the tape while it was delivering current. This power was approximately 5 milliwatts while the output of the tape was 1.3 watts. Even with motor and drive inefficiencies, it is obvious that on a power basis alone the tape can operate the parasitic drive without significant power loss. The problem in this next phase of the work will be to design a light, milliwatt power drive to operate efficiently in these low power ranges.

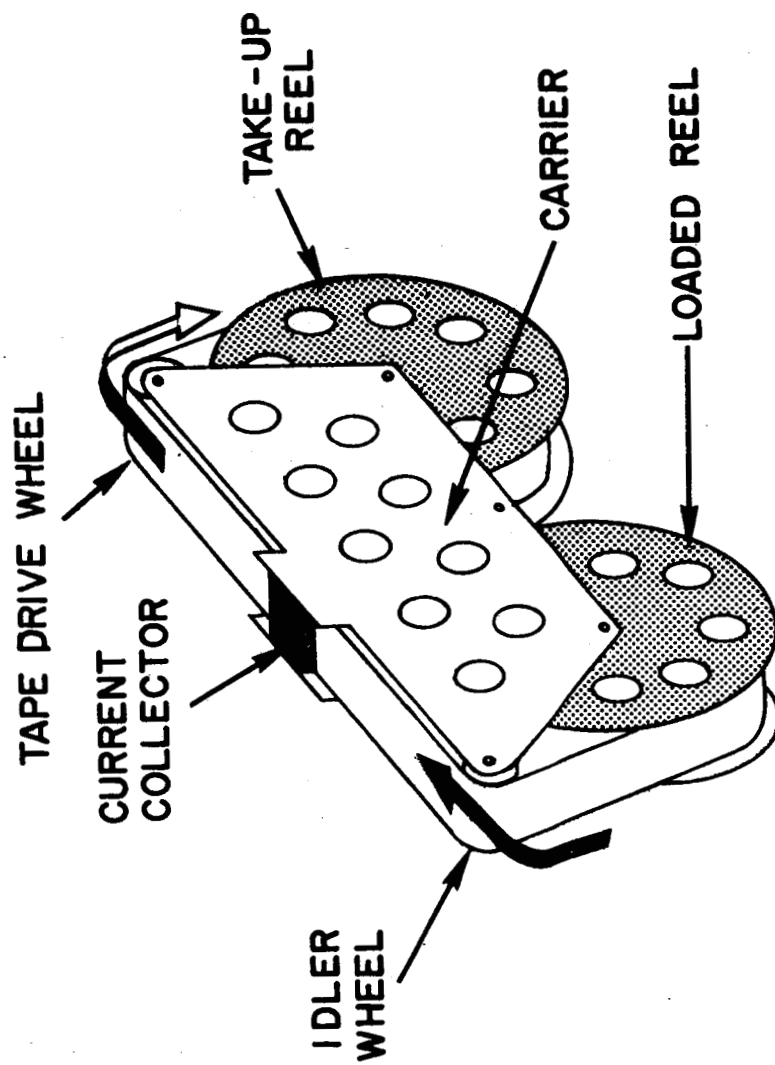
D. Multiple Cell Voltage

Despite terminology, all previous discussion has dealt with unit cells rather than multiple voltages or battery power packages. Work in this area is planned during the next phase. There are three general ways of providing for a system with higher voltages.

The first employs a voltage conversion device external to the electro-chemical system. While this method remains a distinct possibility, it is felt that the necessary high conversion efficiency of such a device would require it to be designed around a constant load. It would presumably be operable under a varying load, but the efficiency would suffer.

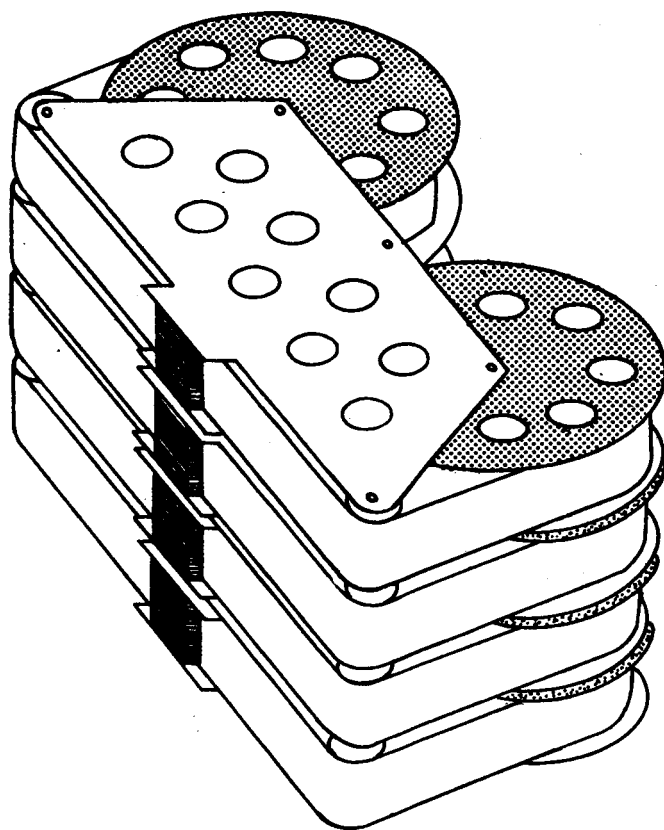
The second method of obtaining higher voltages would be to use bi-polar or duplex electrodes. While this method offers unique advantages, its major application appears to be for low current devices since any duplexing of tapes would of necessity increase the tape thickness and decrease its flexibility to such an extent that operation between the current collectors might suffer. For example, for a bi-polar tape system operating at 5 amperes and 28 volts, the tape thickness would be approximately 1/4". This would be a rather inflexible tape. However, there is the possibility of storing individual tapes on separate reels and duplexing them just before they enter the current collectors.

The third method of providing multiple cell voltages is perhaps the most obvious one, that of series connecting individual tape deck modules. A schematic drawing of a single module is seen in Fig. 17 while a 4-cell stack is shown in Fig. 18. Each stack of cells would be powered by a parasitic electrical drive mounted on the end plate of the stack. In the next phase of the development work on the tape concept this stacking principle will be used for providing multiple cell voltages.



SINGLE CELL TAPE MODULE

FIGURE 17.



STACKED CELLS

FIGURE 18.

VI. SYSTEM APPLICATIONS

The foregoing information has been concerned with tape system concepts, the accomplishments to date, and objectives for future work. Discussed briefly below are possible applications where dry tape batteries offer some advantages over existing systems.

A. High Energy Density Couples

The tape system should lend itself to the use of extremely high energy density electrochemical couples which cannot now be used in conventional battery systems.

B. Programmed Power

With the tape concept it should also be possible to provide programmed power systems by using variable speed drives. The speed of the drive could either be preprogrammed or it could be controlled by the load demand. This would result in high electrochemical efficiencies under varying loads.

C. Reserve Systems

Present reserve battery systems are used for high rate and/or high energy density couples. Activation of these systems is generally total in that the reserve properties are destroyed and a finite shelf life begins. With the dry tape it is possible to use reserve couples by activating just as much of the system as is needed. It isn't necessary to activate all of the electrochemical capacity at once.

D. Secondary Systems

The tape concept should also be applicable in secondary systems. The advantage gained here is that two sets of current collectors or electrodes can be used.....one of a low area for discharge at high current densities and a second set elsewhere in the system with high area for low current density charging.

E. Constant Voltage Operation

There is a very good possibility of using the dry tape concept to provide a constant voltage device by using variable collector areas. In this case we would utilize a constant tape speed and the current collectors would be incorporated on the edge of a cam. By rotating the cam through a fixed number of degrees we could then change the area of contact with the tape.

F. Thermal Systems

There is no reason why thermal battery systems could not also be applied to tape. In this case the system could be activated by incorporating match compositions within the tape so that as it entered the current collectors the friction would cause ignition, thereby melting the salt electrolyte. It shouldn't be too difficult to prevent the match from flashing back along the unused tape.